EUV lithography

NXE platform performance overview

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2014 SPIE Advanced Lithography, San Jose CA, 9048-54

Contents

ASML EUV technology roadmap - extendibility

Extend NA 0.33 to below 10nm

Improved lens and illuminator performance

Imaging / Overlay performance match node requirements

Increased throughput at higher dose

		32	27	22	16	13	10	7	<7
						Under study			
Resolution/HP [nm]		32	27	22	16	13	10	7	<7
Wavelength [nm]		13.5							
Lens	NA	0.25		0.33			0.33NA DPT		
								>0.5NA	
	flare	8%		6%	4%				
Illumination	coherence	σ=0.5	σ=0.8	σ=0.2-0.9	Flex-OAI	Extended Flex-OAI			
						reduced pupil fill ratio			
Imaging	CDU [nm]	-	2.0	1.7	1.3	1.1	1.0	0.9	
Overlay	DCO [nm]	7	4.0	3.0	1.5	1.4	1.2	1.0	
	MMO [nm]	-	7.0	5.0	2.5	2.0	1.7	1.4	
TPT (300mm)	Dose [mJ/cm^2]	5	10	15	15	20	20		
	Power [W]	3	10 - 105	80 - 250	250	250	500		
	Throughput [W/hr]	-	6 - 60	55 - 125	125	125	165		

pupil fill ratio defined as the bright fraction of the pupil

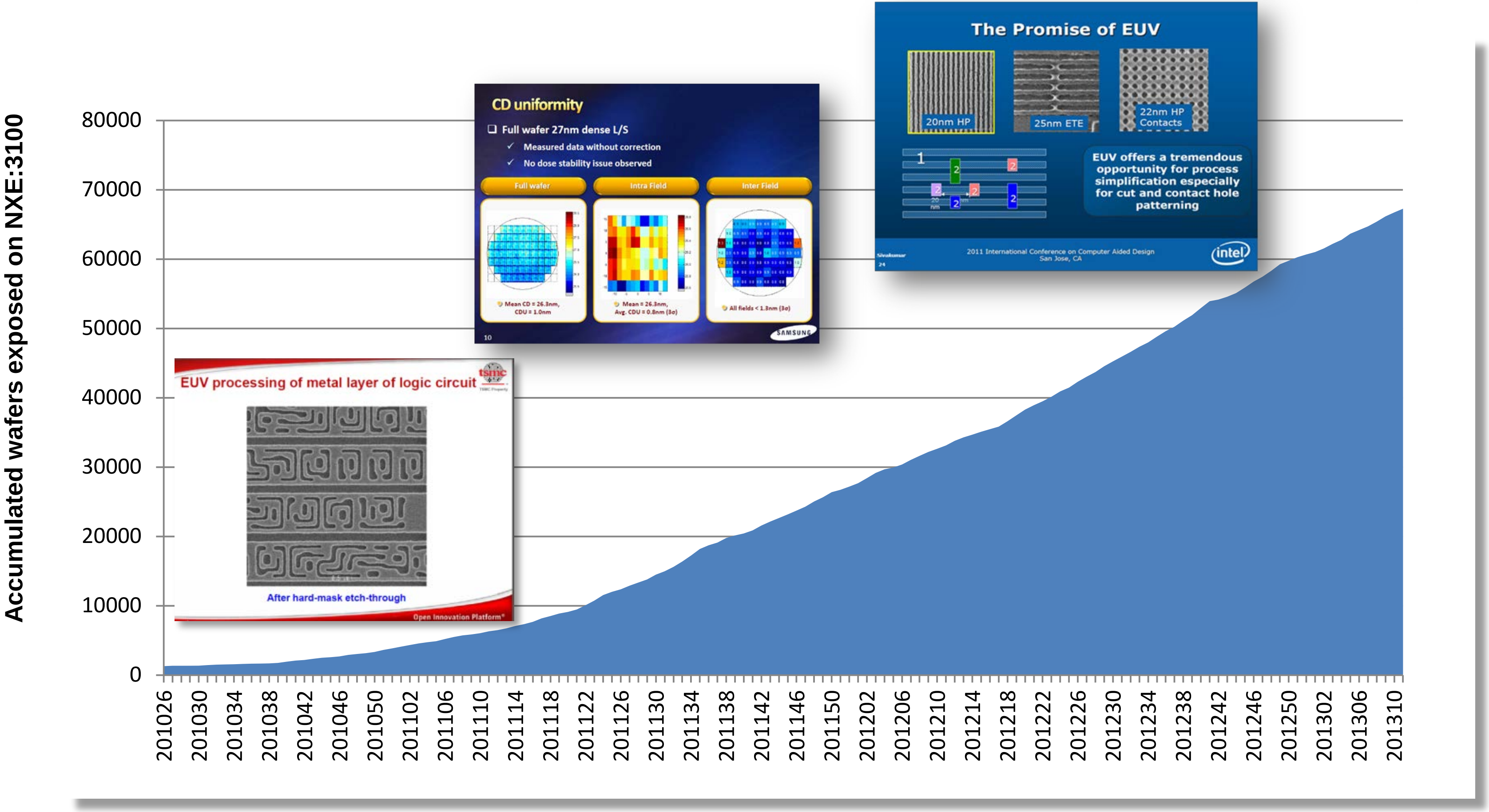
ASML’s NXE:3100 and NXE:3300B

	NXE:3100	NXE:3300B shipments started 2013
NA	0.25	0.33
Illumination	Conventional 0.8σ	Conventional 0.9σ, 6 off-axis pupil settings
Resolution	27 nm	22 nm
Dedicated Chuck Overlay / Matched Machine Overlay	4.0 nm / 7.0 nm	3.0 nm / 5.0 nm
Productivity	6 - 60 Wafers / hour	55 - 125 Wafers / hour
Resist Dose	10 mJ/cm^2	15 mJ/cm^2

Contents

NXE:3100 in use for cycles of learning at customers

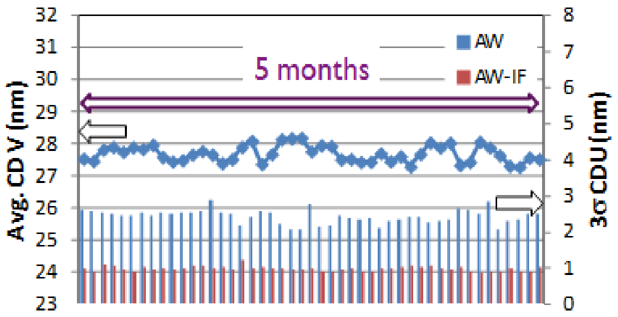
6 systems operational at customers



NXE:3100 shows stable performance

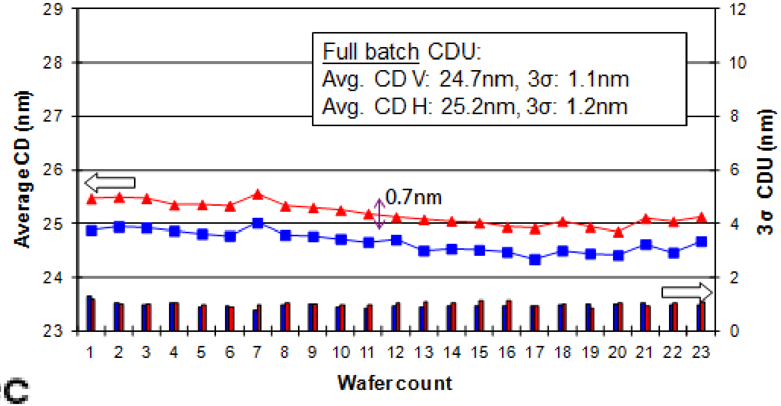
LONG TERM WAFER STABILITY OF 27nm V LS - NOV'12-APR'13, CONV.ILL. 14MJ/CM2, YIELDSTAR S200

71 fields/wafer, 26x33mm², 5x3 intrafield sampling



FULL BATCH CD UNIFORMITY OF 27nm LS

23 wafers, 83 fields/wafer, 1 point/field, Hitachi CG-4000



imec

Data courtesy of imec – EUVL Toyama 2013

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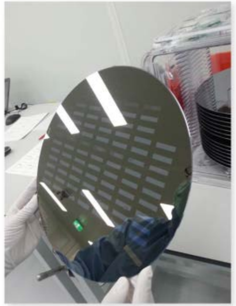
EUV (NXE:33x0B) system status overview



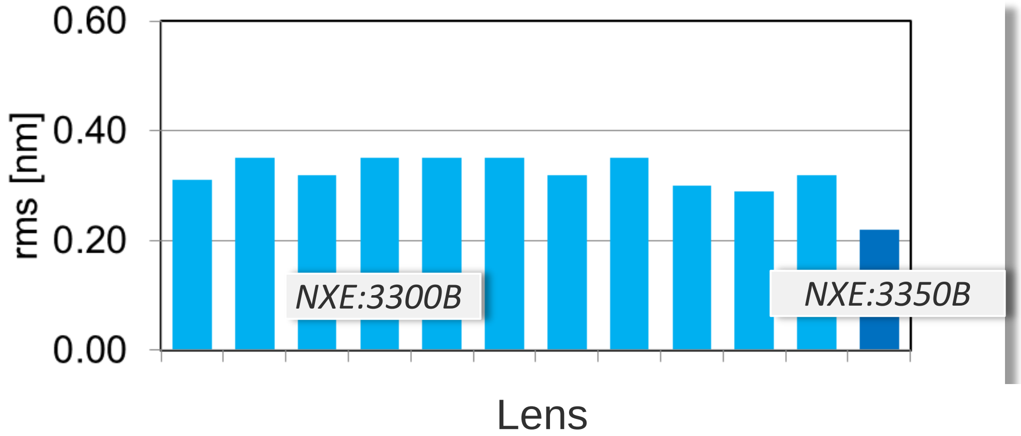
- Multiple NXE:3300B systems fully qualified
  - 2 systems exposing wafers at the customer sites
  - Install has been started for 3 systems

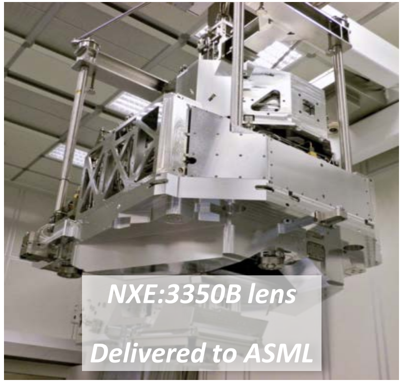
- 6 more NXE:3300B systems being integrated
- 4th generation NXE system (NXE:3350B) integration ongoing

- EUV cleanroom extension is under construction

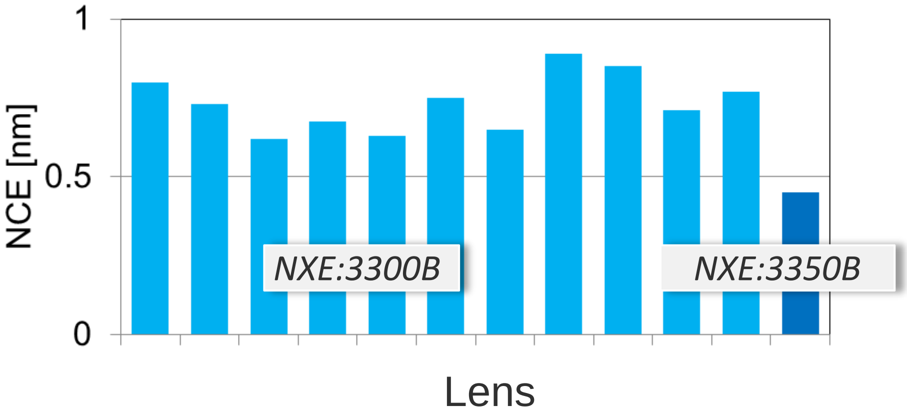
Consistent and reproducible NXE:33x0B lens performance

wavefront rms





lens NCE



Every bar is an individual lens

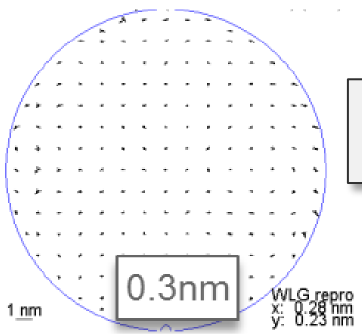
Data courtesy of Carl Zeiss SMT GmbH

Based on Zeiss input and does not include scanner contributions

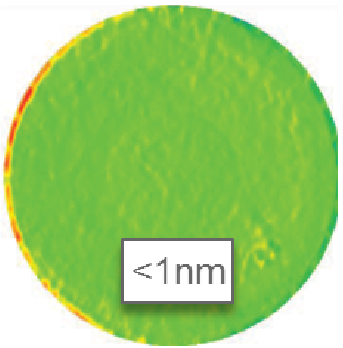
NCE = Non Correctable Error

Contents

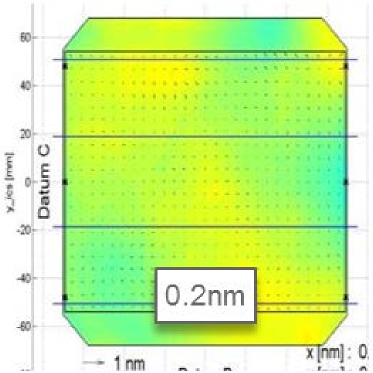
Overlay improvements implemented on NXE:3300B



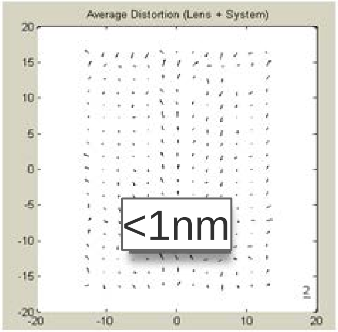
wafer load grid performance



wafer clamp flatness

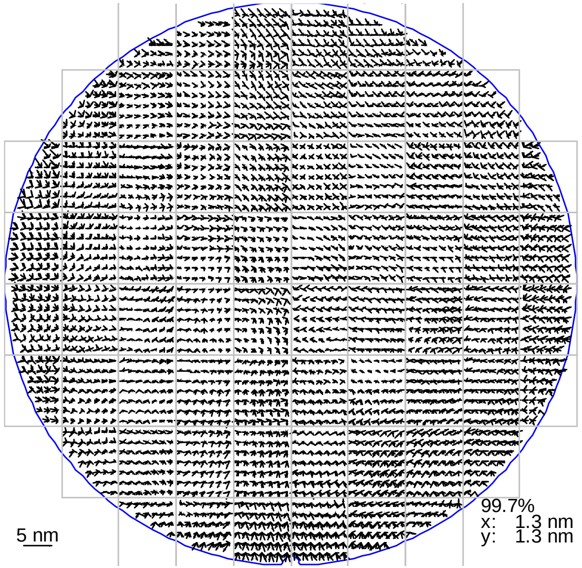


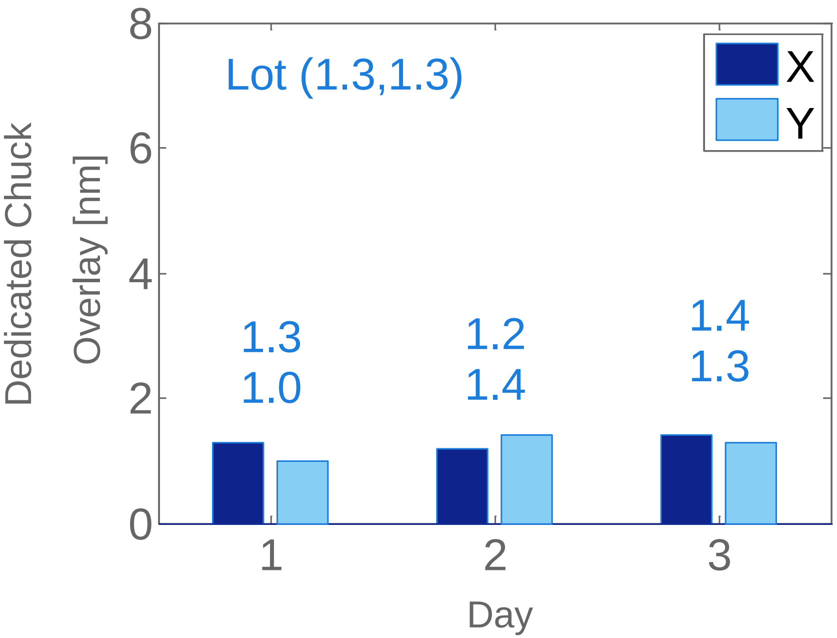
reticle clamp flatness



lens performance

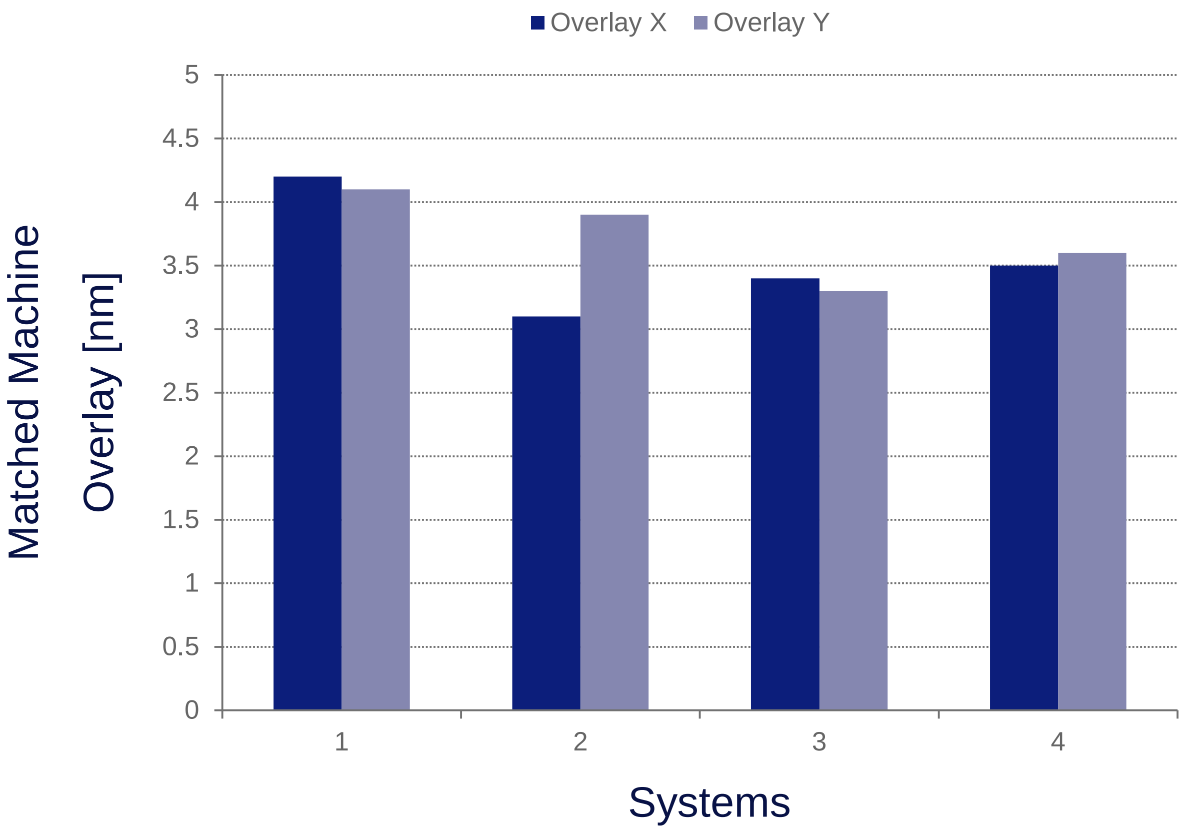
Full wafer dedicated chuck overlay of <1.4nm

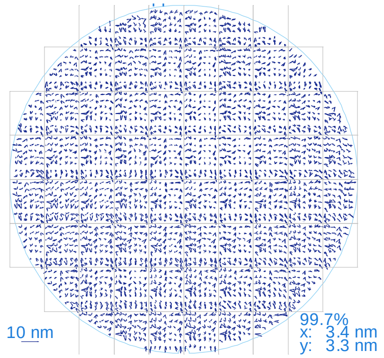




- Layers are exposed on the same wafer on the same chuck over multiple days
- Dedicated chuck overlay is a measure of the overlay performance of the system

Good full wafer matched machine overlay performance on multiple systems (NXE:3300B to immersion)





- Grid matching using different reticles
- Intrinsic design differences
  - Projection optics
  - Reticle clamping
  - Wafer clamping

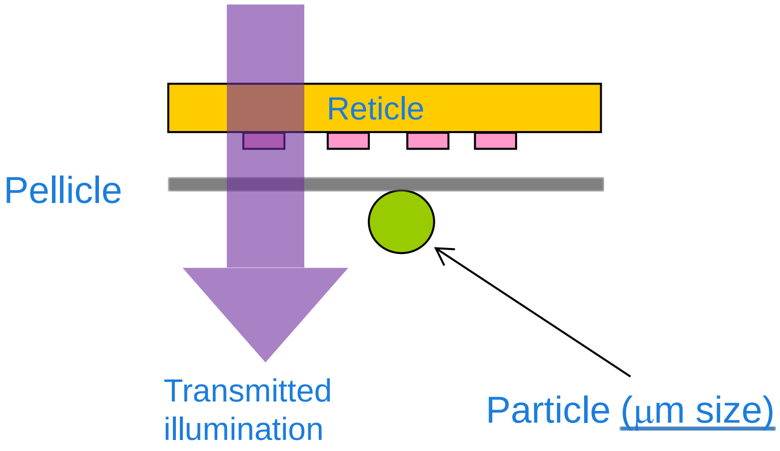
See Jan Mulkens 9048-56

Contents

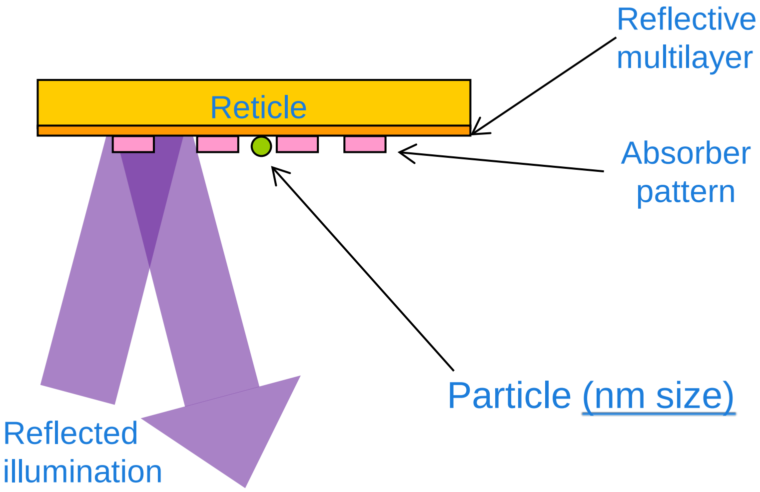
The mask defect challenge

Challenging defect requirements on reflective EUV mask without pellicle

DUV Reticles (193nm)



EUV Reticles (13.5nm)



Current defectivity qualification test for particles on the front side of the reticle - particles per reticle pass (PRP)

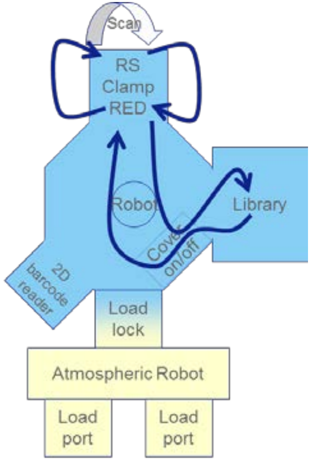
Particle per Reticle pass test

Load reticle

into scanner

Pre-measure reticle

Cycle reticle/wafers



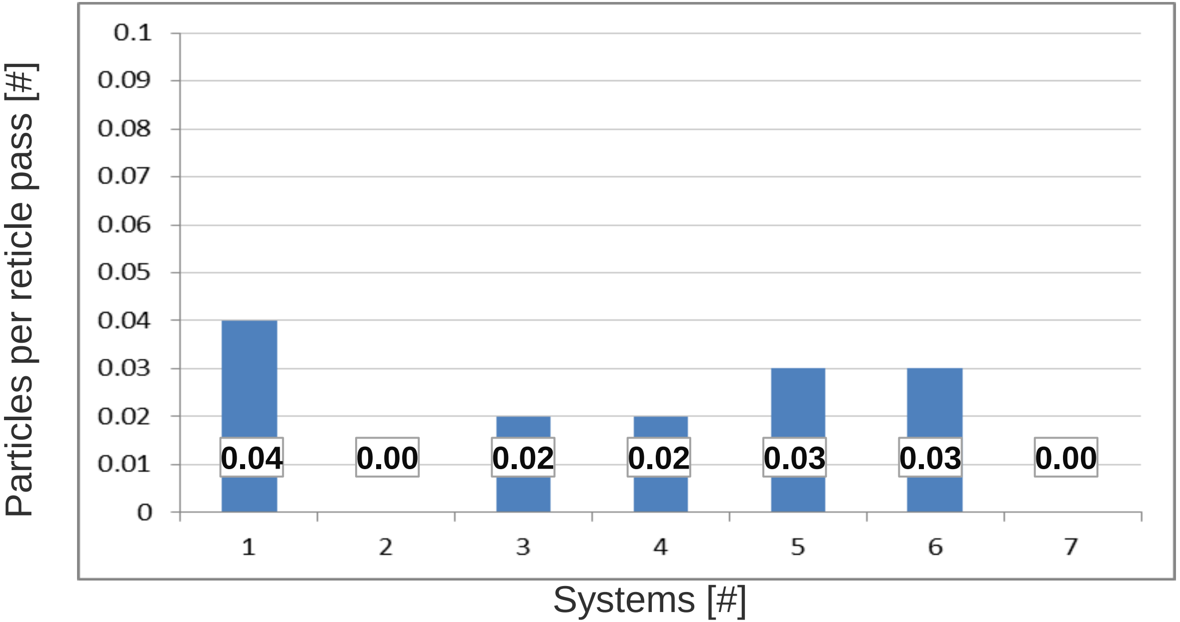
Take reticle

out of scanner

Post-measure reticle

- Reticles and wafers are cycled under exposure conditions without light therefore executable also in integration phase
- The test shows all particles that come onto the front-side of the reticle during the complete reticle cycle (off-line measurements / in-scanner cycling)
- Particles added during reticle handling outside the scanner system can not be excluded
- Particles on reticle level are not tested for printability on wafer level

System level testing for Particles Per Reticle Pass (PRP) is done simulating production use during integration at ASML

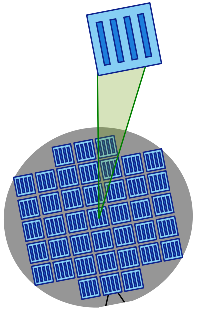


# LOTs	23	42	100	115	144	100	30
# Wafers	345	630	1500	1725	2160	1500	450
Total # particles	1	0	2	2	5	3	0

- Multiple NXE:3300B systems
- Measured at >92nm sensitivity
- During integration phase actions are done on the system which can lead to variations in test result
- PRP 100x test duration is ~20 hours

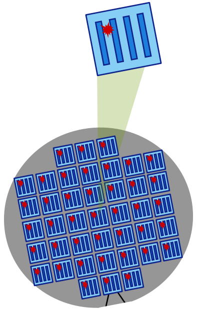
New imaging PRPi test focuses on printability of reticle defects on wafer level and excludes outside scanner reticle handling

Expose PRPi
***pre* reticle cycle wafers**



Expose 32nm line-space defectivity reticle

Expose PRPi
***post* reticle cycle wafers**

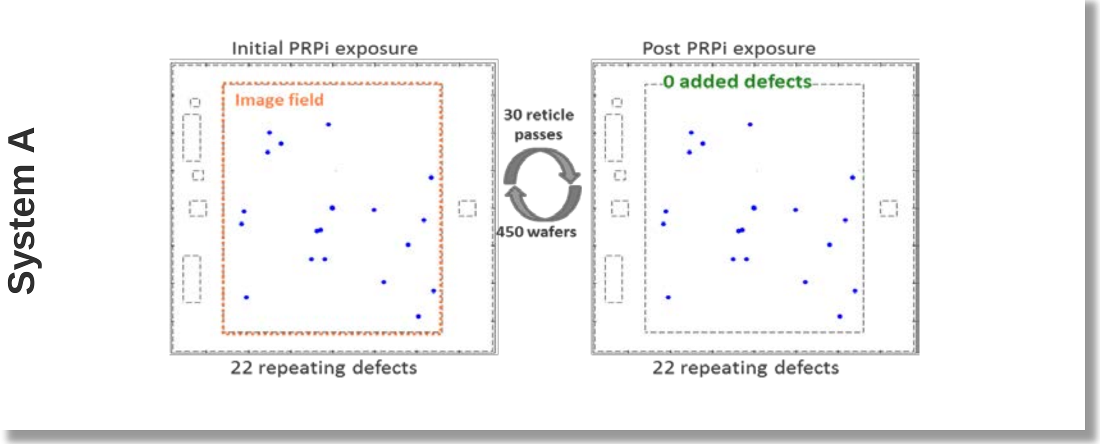


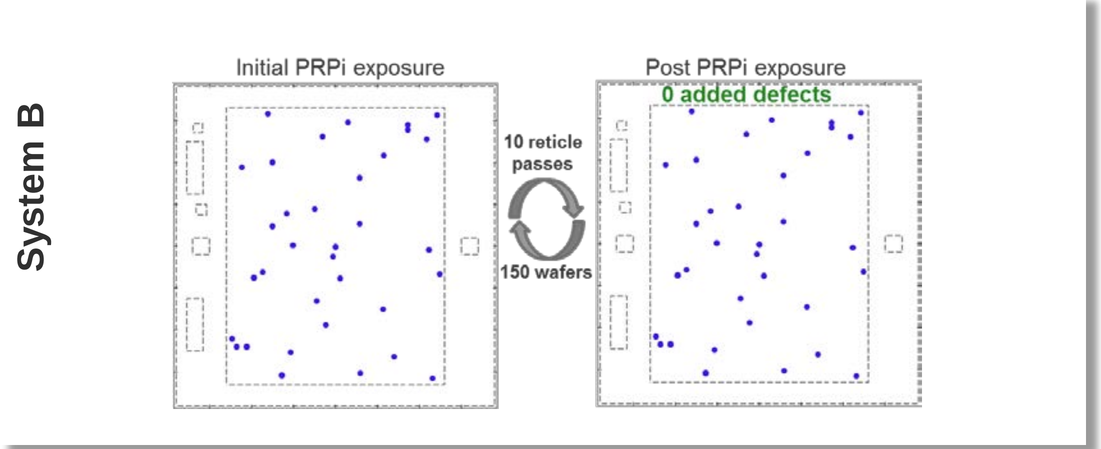
Expose 32nm line-space defectivity reticle

The imaging PRP test

- Uses a location based analysis and provides information when a particle during the exposures gets onto the front side of the reticle
- Therefore, if a particle is generated in the system it can be determined when and where this particle has been generated

Early NXE:3300B test results from PRPi test are promising

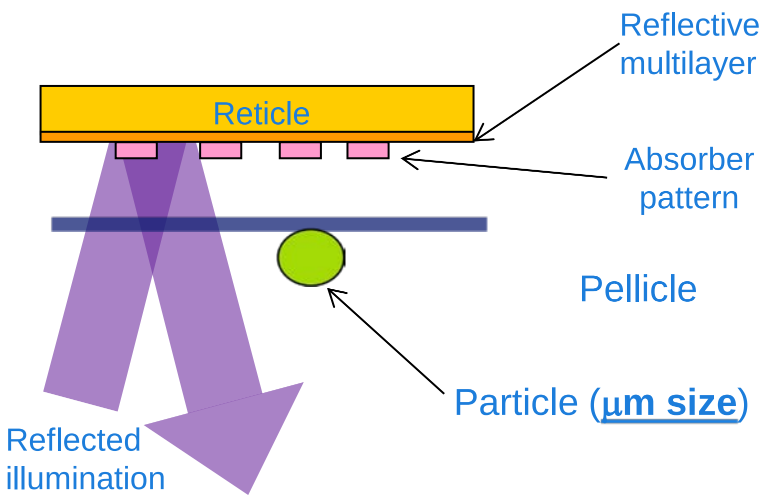


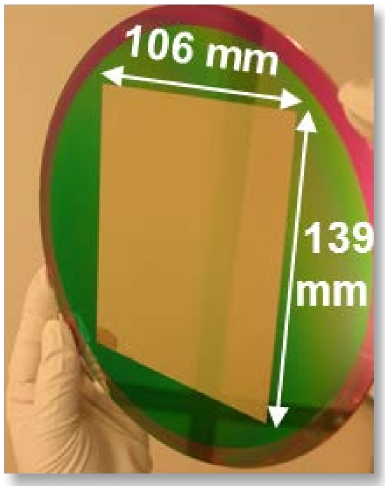


- Early test performed on two systems using a test reticle (not a production reticle)
- **Repeated defects** (blue dots in the figures) observed already present during initial PRPi exposure
- Repeated defects are a combination of reticle absorber defects and multilayer defects, and particles already present on the reticle during initial exposure
- **No added defects** on frontside of the reticle found during simulated wafer exposures
- Extended build-up of statistics ongoing

Progress continues in EUV pellicle development

EUV Reticles (13.5nm)





First prototype full size free-standing pSi pellicle in progress

See Carmen Zoldesi 9048-58

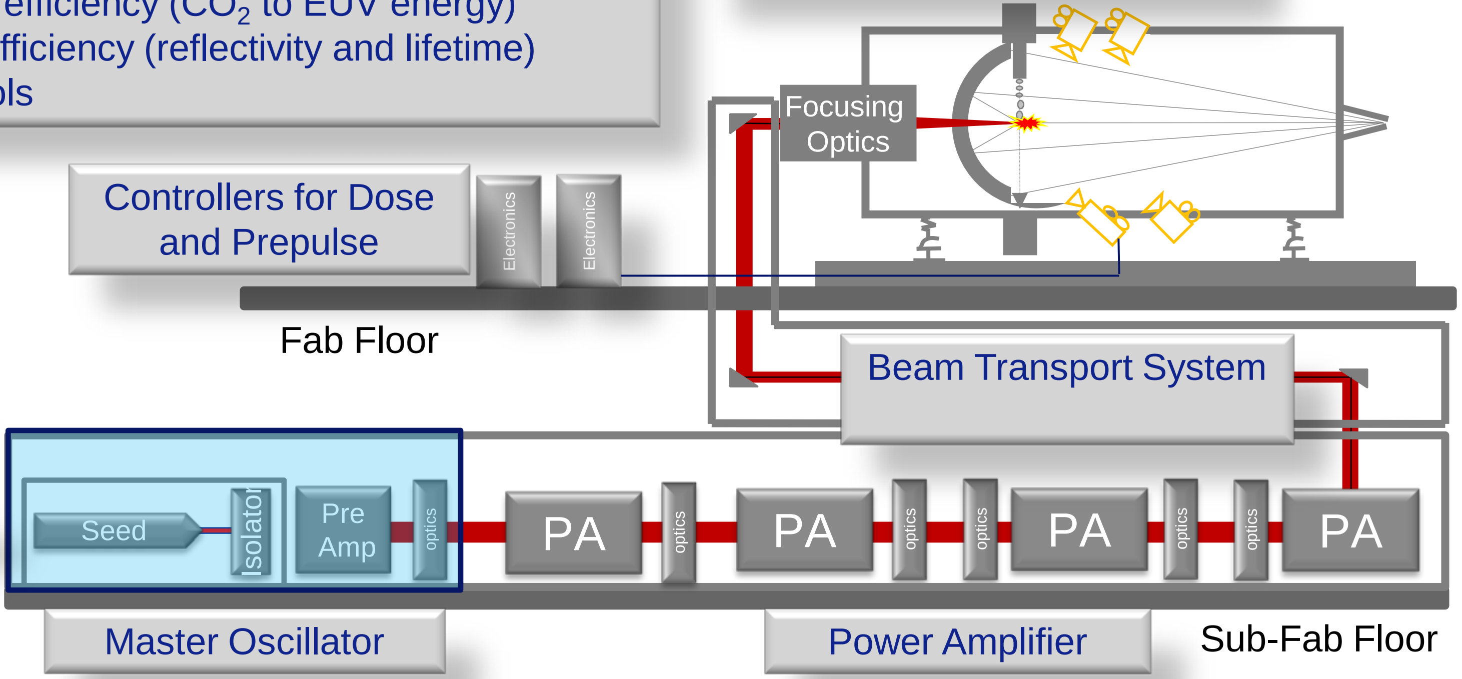
Contents

MOPA Prepulse Source Architecture

- Key factors for high source power are:
  - High input CO2 laser power
  - High conversion efficiency (CO_2 to EUV energy)
  - High collection efficiency (reflectivity and lifetime)
  - Advanced controls

Vessel
With Collector, Droplet Generator and Metrology

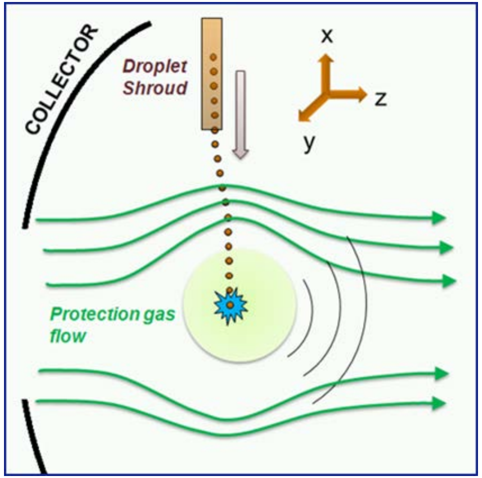
Prepulse requires seed laser trigger control



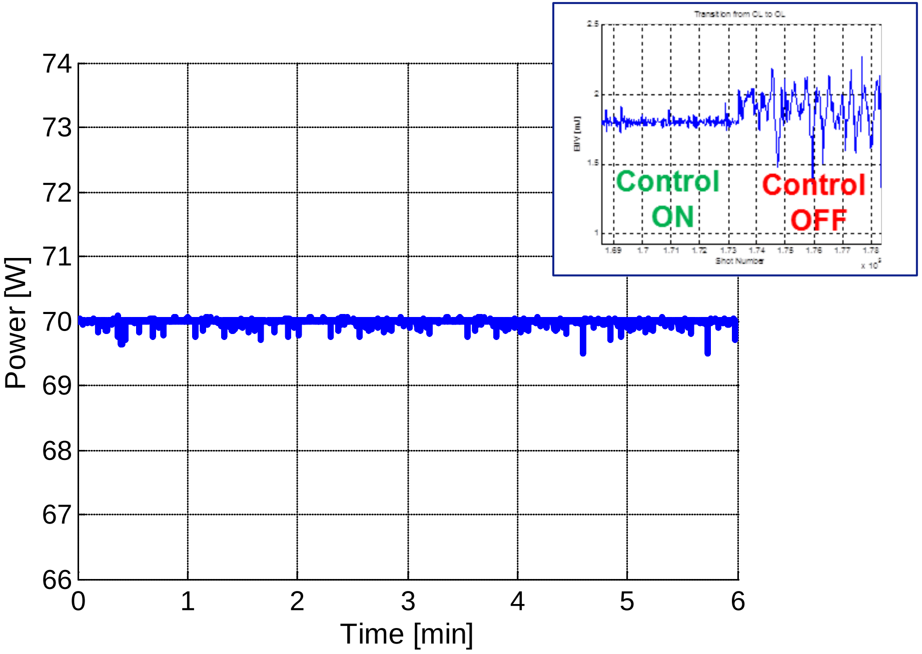
MOPA - Master Oscillator Power Amplifier

Technology Demonstration: 70W power using MOPA+PP

Dose margin >3.5x reduced using advanced dose control



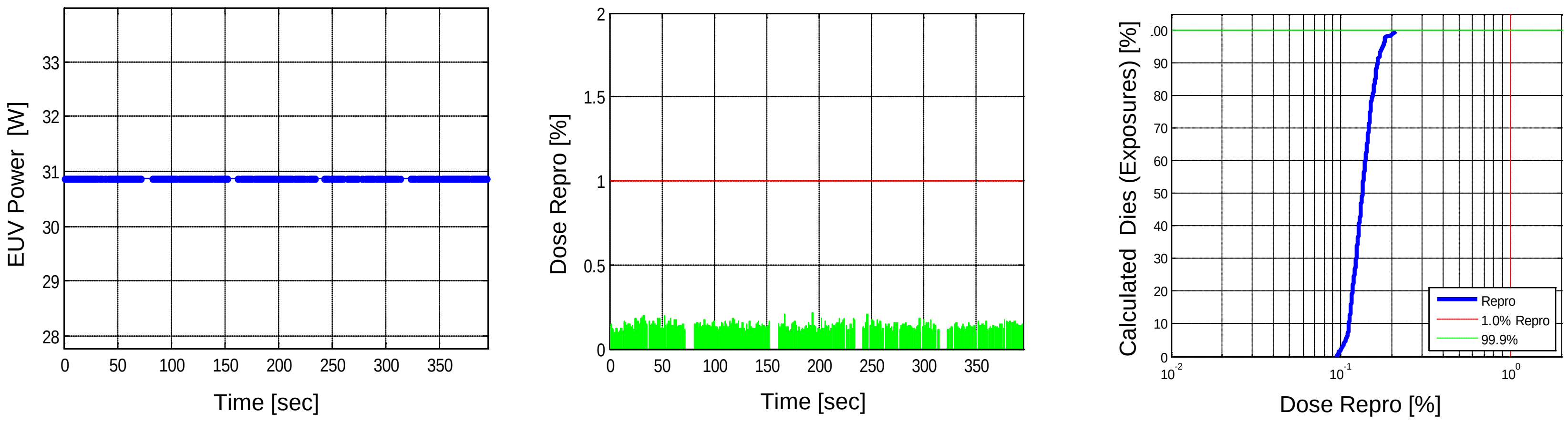
- Plasma and gas-dynamic forces distort droplet trajectories causing energy instability
- Controls that compensate for all forces enable closed loop operation with reduced dose margin
- Dose margin is the difference between unstabilized open loop power and stabilized closed loop power



Data taken on MOPA Prepulse development source

Industrialization: 30W EUV power on a production source

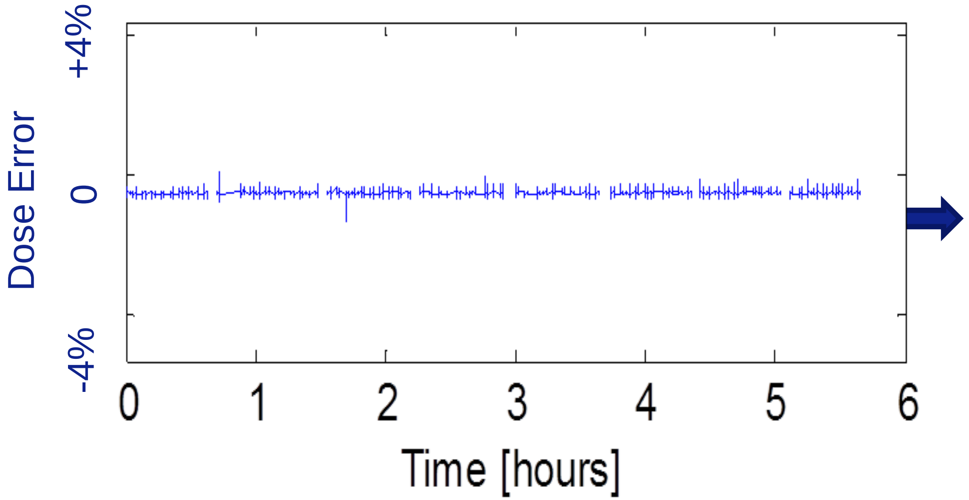
NXE:3300B MOPA+PP source operated in automated mode

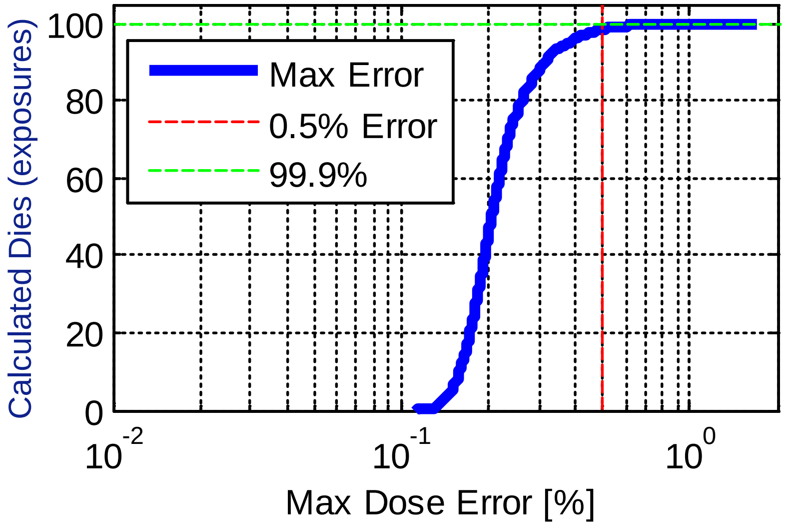


- 30W dose controlled power, with 100% die yield (percentage simulated dies meeting the 0.5% dose repro specification)
- Results shown using ~18kW drive laser power
- NXE:3300B sources in the field have ~22kW drive laser power capability

Industrialization: Stable source operation is key

Dedicated test run:XE:3300B MOPA+PP source operating in automated mode for 6hrs continuously within dose spec. Fully automated for Fab operations

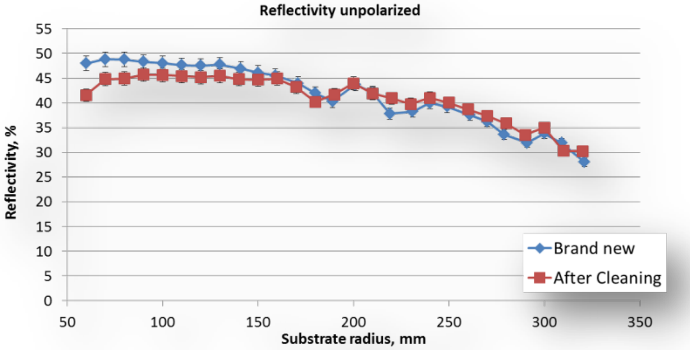




- Dedicated stability test run, slightly different settings and power as on previous slide
- 99.9% die yield (percentage simulated dies meeting the 0.5% dose repro specification)
- Stable source operation: Automation, start-up routines, recovery routines, diagnostics and closed loop controls in x, y, z, t and E

In-situ Collector Cleaning: Technology Proven

Significant improvement to COO and Availability

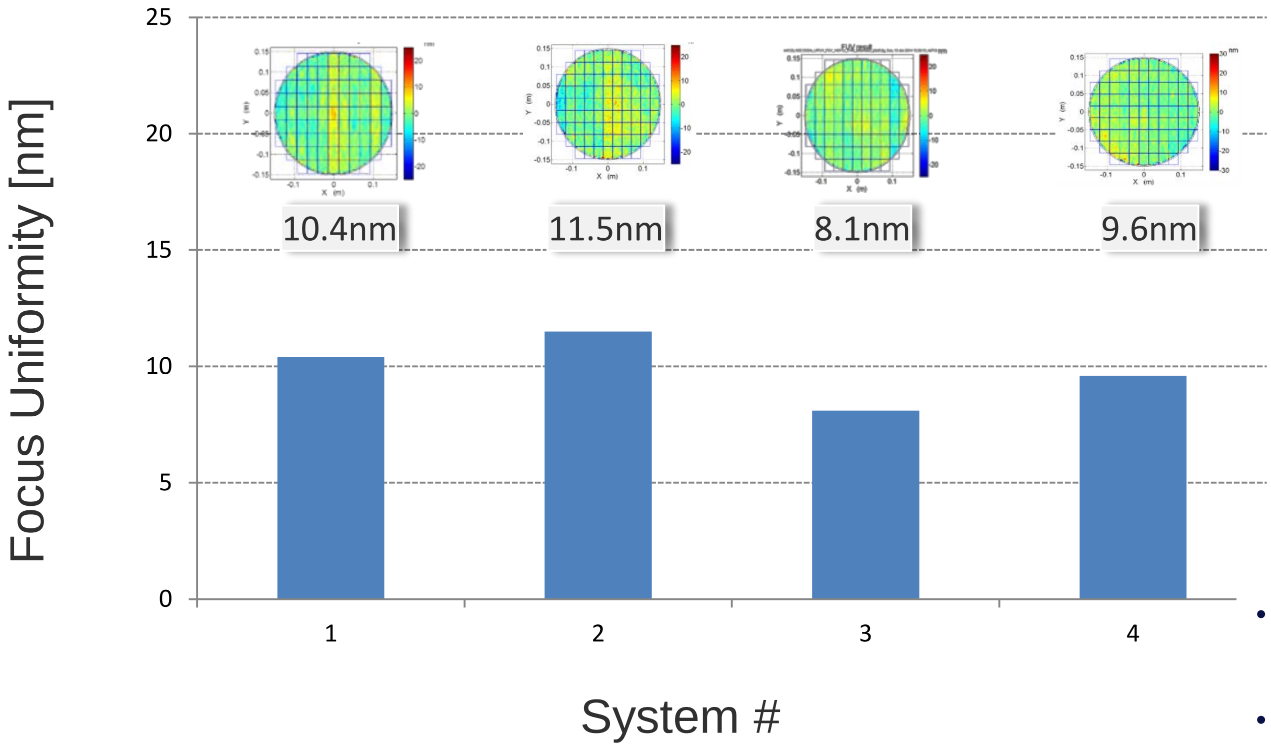


- Reflectivity after cleaning compared to ‘as new’
- Measurements on different reflectometers and sample locations

Full collector in-situ cleaning capability demonstrated with NXE:3300B compatible configuration

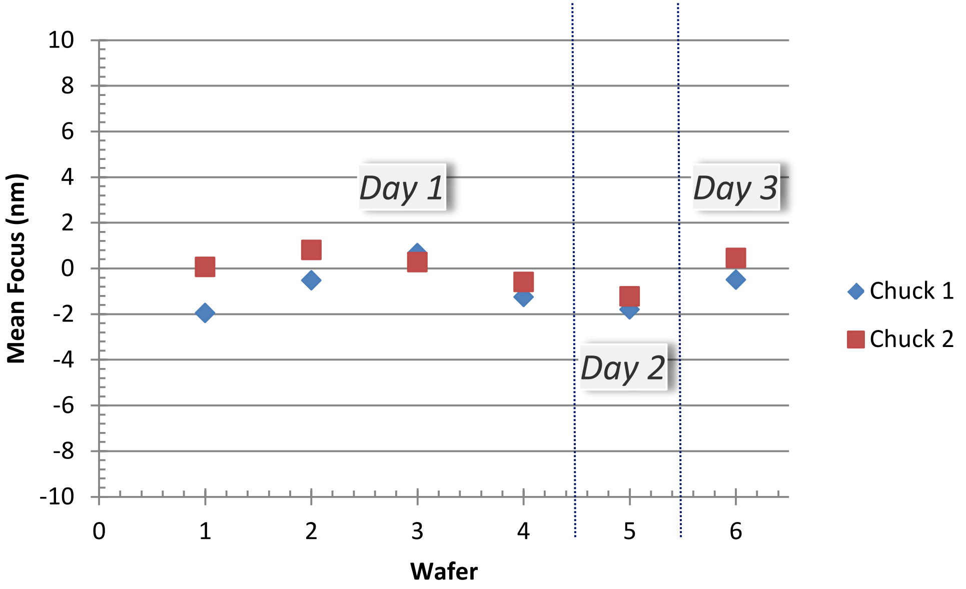
Contents

NXE:3300B full wafer focus uniformity <12nm



- The focus uniformity performance test is done in resist
- Focus sensitive marks are being exposed to obtain full wafer coverage information

3-day Focus Stability of 2.4nm on NXE:3300B



Focus Stability:

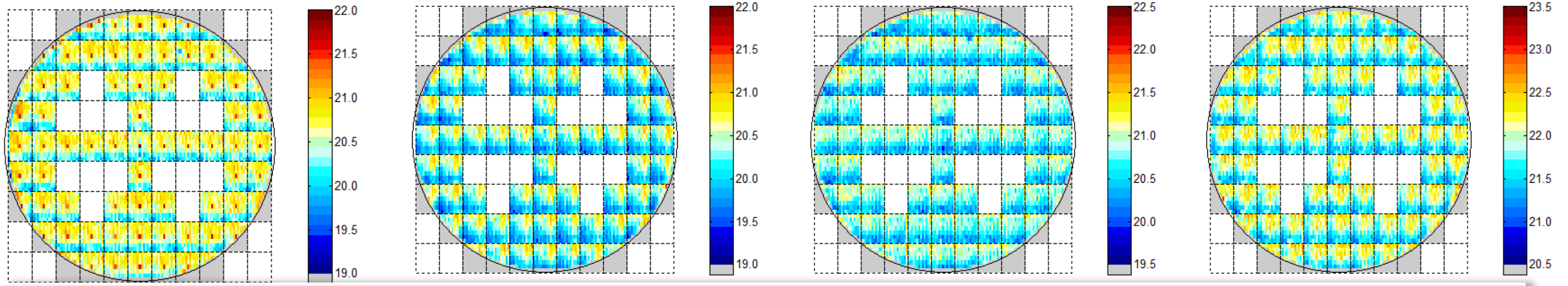
- 3-day Mean Focus range over both chucks
- Per wafer 16 fields are exposed
- 3-day Focus Stability of 2.4nm

Multiple systems show NXE:3300B CDU below 1.6nm

dense and iso lines exposed at 16mJ/cm2

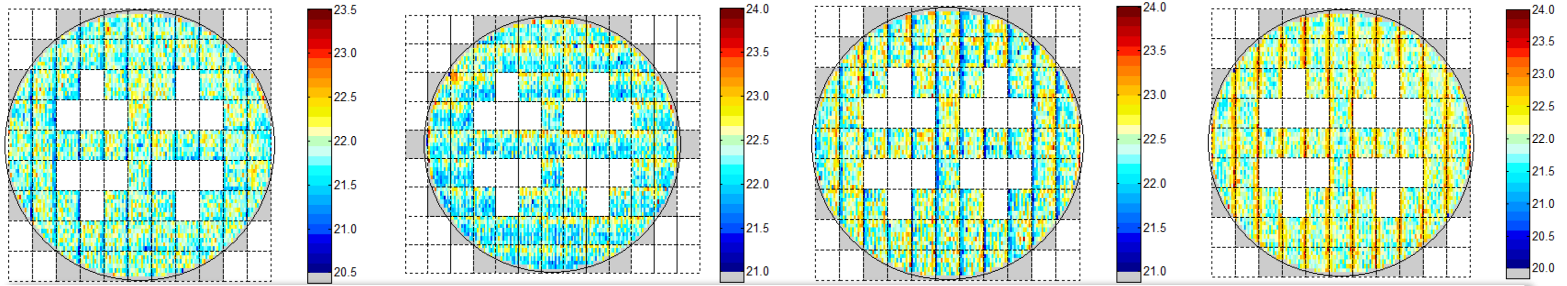
System A | System B | System C | System D

22 nm DL



Full wafer CDU <1.2nm

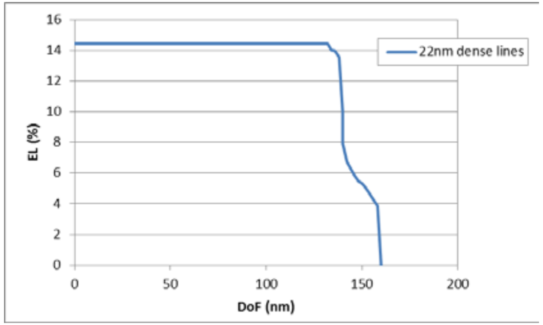
22 nm IL



Full wafer CDU < 1.6nm

CD measurements performed with YieldStar

22nm dense and iso L/S with an exposure latitude of >14%



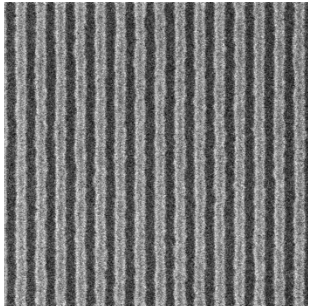
Conventional illumination

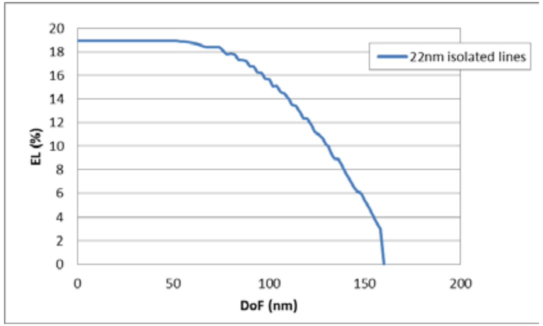
BE = 16 mJ/cm2

LWR = 3.8nm

Exposure Latitude > 14%

DoF > 100nm





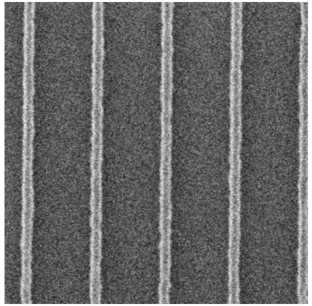
Conventional illumination

BE = 16 mJ/cm2

LWR = 3.4nm

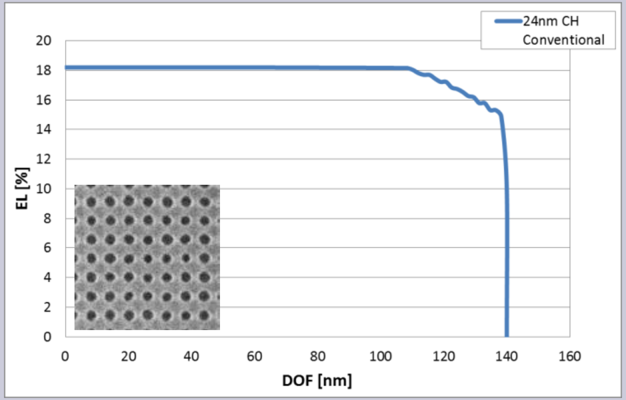
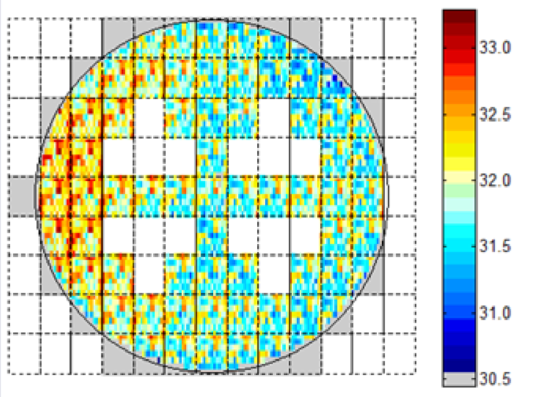
Exposure Latitude > 14%

DoF > 100nm



No post processing done

24nm regular contact holes (~18nm node DRAM) with conventional illumination *Large process window and 1.2nm FWCDU*

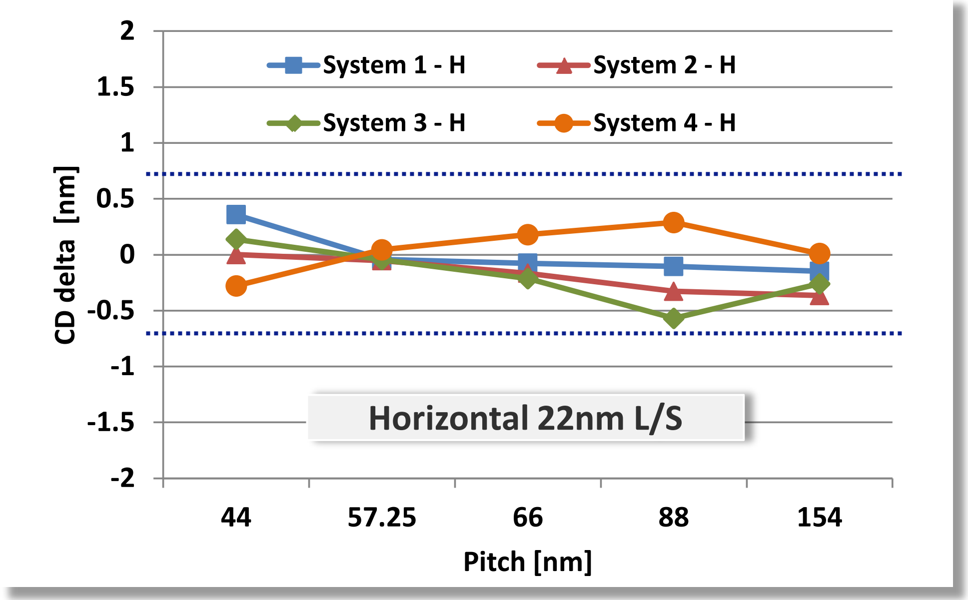
Process Window	Full wafer CD uniformity
	
Exposure latitude 18% DoF > 120nm	Full wafer CDU: 1.2nm 3σ

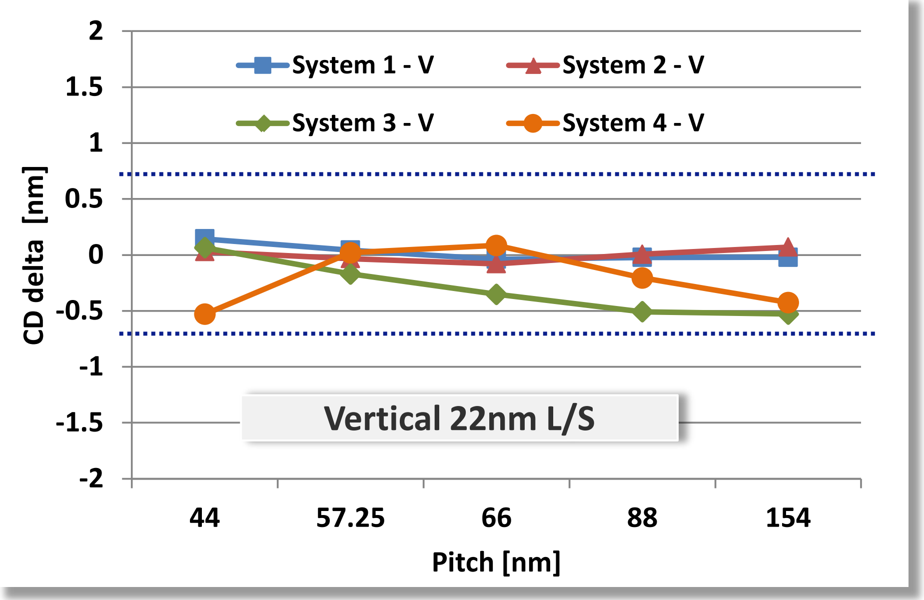
- Systematic fingerprints dominated by reticle and process
- Yieldstar measurements

NXE:3300B proximity matching performance

ASML

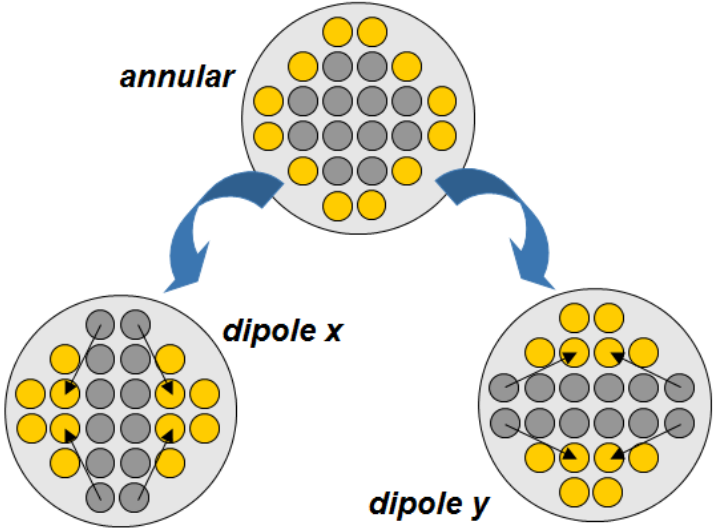
Public



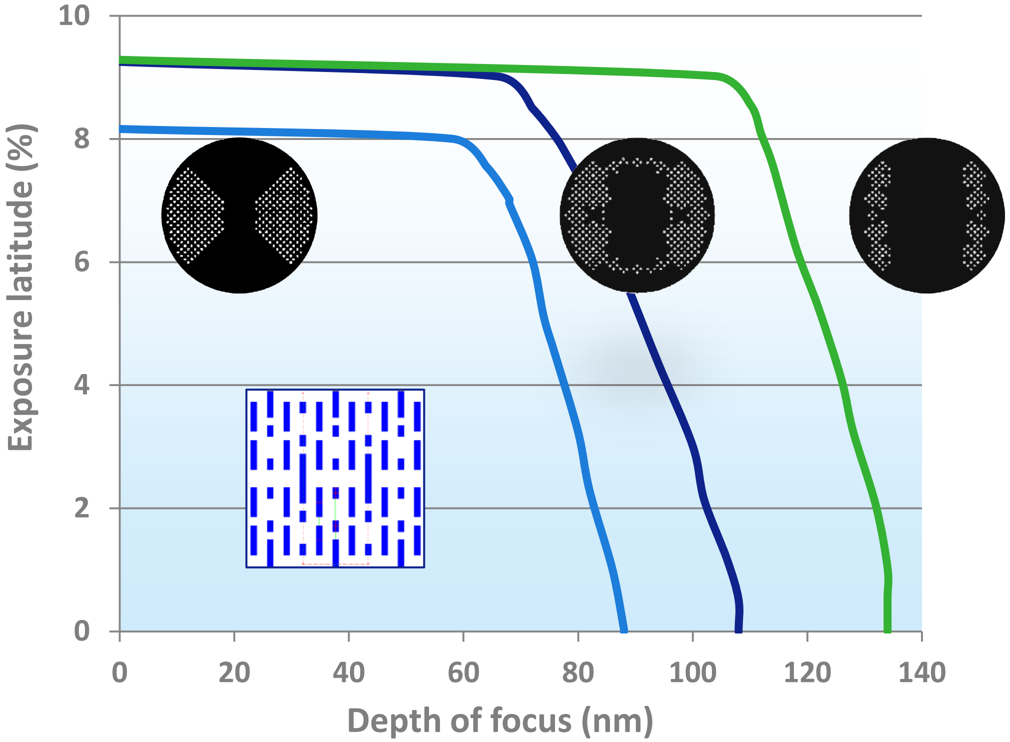


- Data shown with respect to average over 4 NXE:3300B's
- Per system intrafield CD measured through pitch on multiple fields on the wafer with the same test conditions (mask, resist, test layout)
- Average intrafield CD per pitch is then compared to population average
- Target performance for 22nm L/S is +/- 0.7nm
- Further improvement possible with optimized illumination

The NXE platform offers new concept off-axis illumination to enhance process window



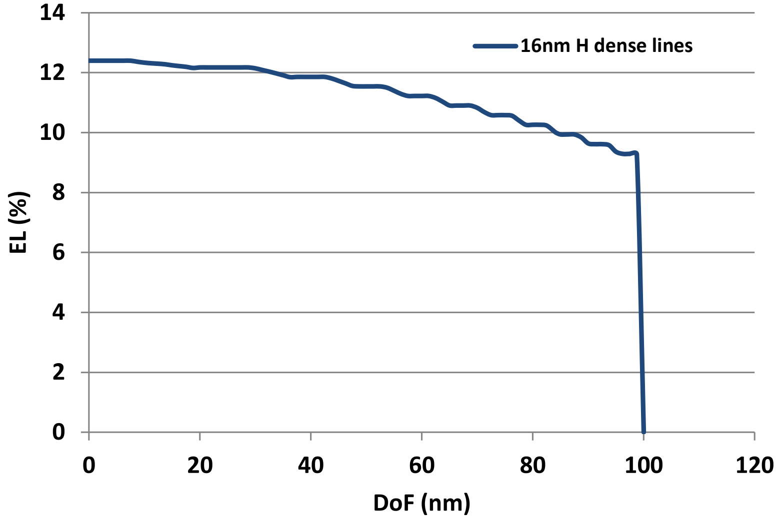
- Flexibel and programmable illumination setting mechanism using fly's eye integrator

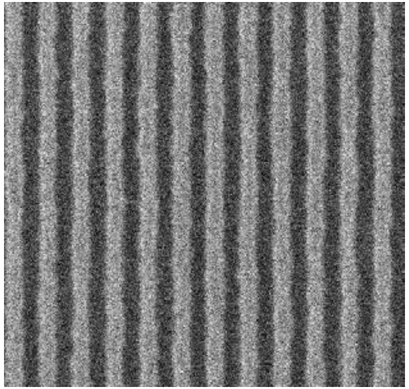


Simulations by Tachyon SMO NXE

See Xiaofeng Liu 9048-025

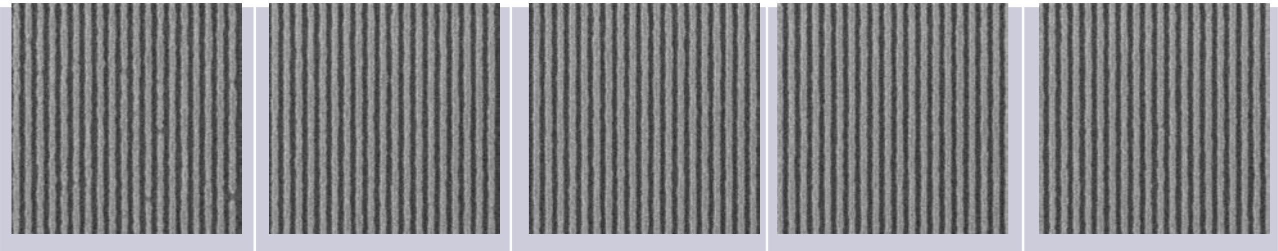
16nm dense lines with >10% exposure latitude on NXE:3300B (dipole-90 setting)





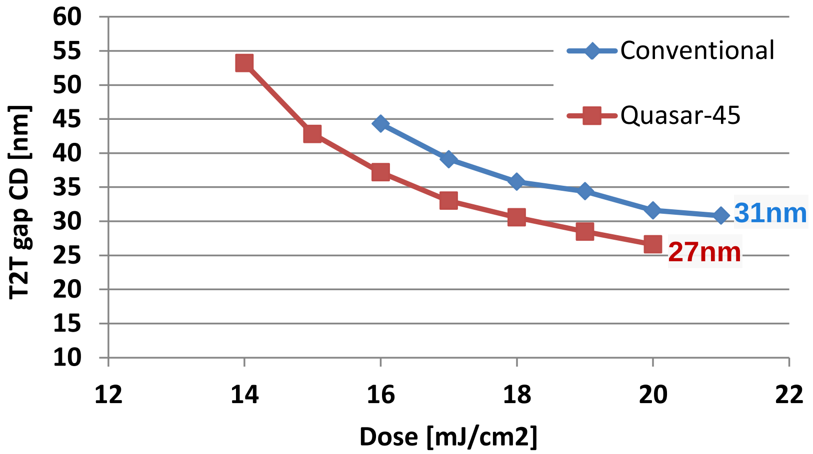
16nm L/S
Dipole 90Y

Focus [nm]	50	25	0	-25	-50

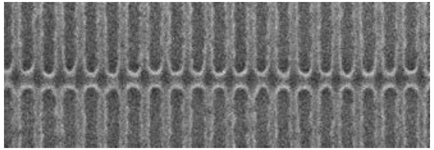


Good logic tip-to-tip and tip-to-line performance at low doses

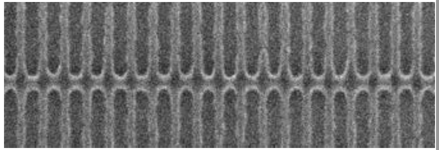
Tip-to-tip



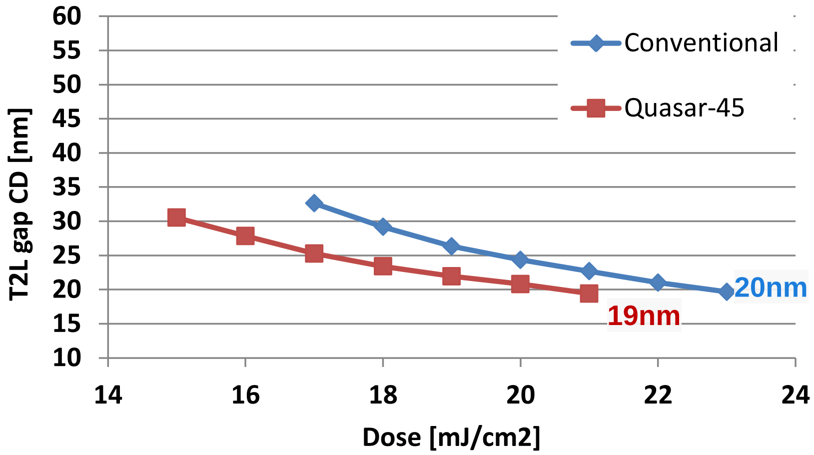
Conv. 31nm



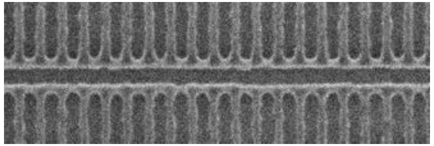
27nm Quasar



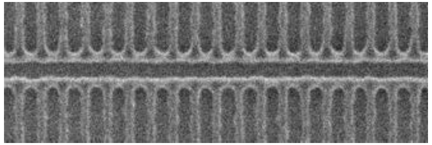
Tip-to-line



Conv. 20nm

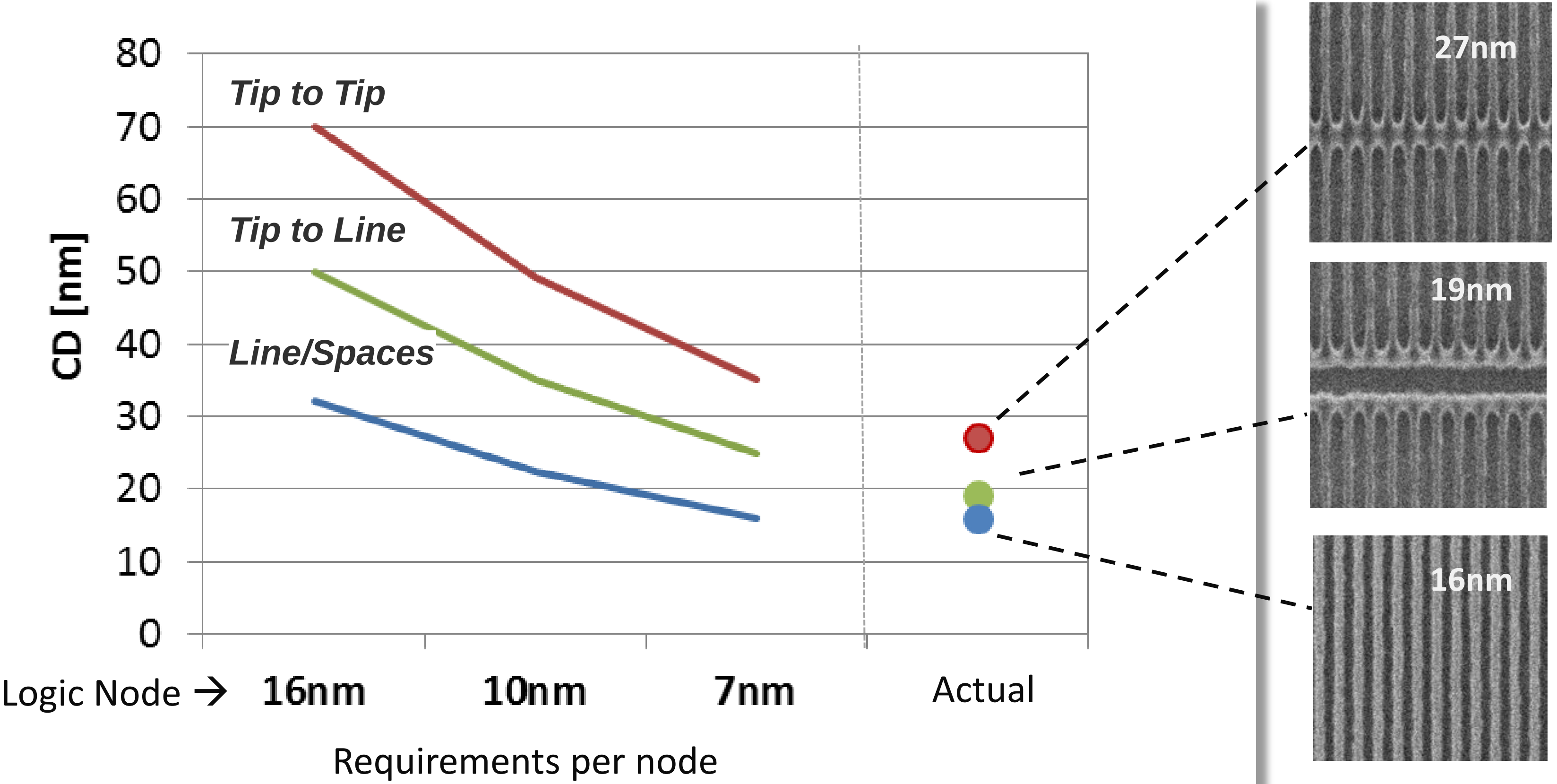


19nm Quasar



EUV single-exposure enables aggressive shrink on 2D logic

shrink possible beyond 10nm Logic node requirement



Random logic metal layer user case

NXE:3300B enables single exposure with large DoF

EUV
▪ Node: Logic 10nm
▪ Single Exposure ▪ Conventional illumination
▪ DoF ≈ 120nm

Position in the exposure slit

-12mm **0mm** **+12mm**

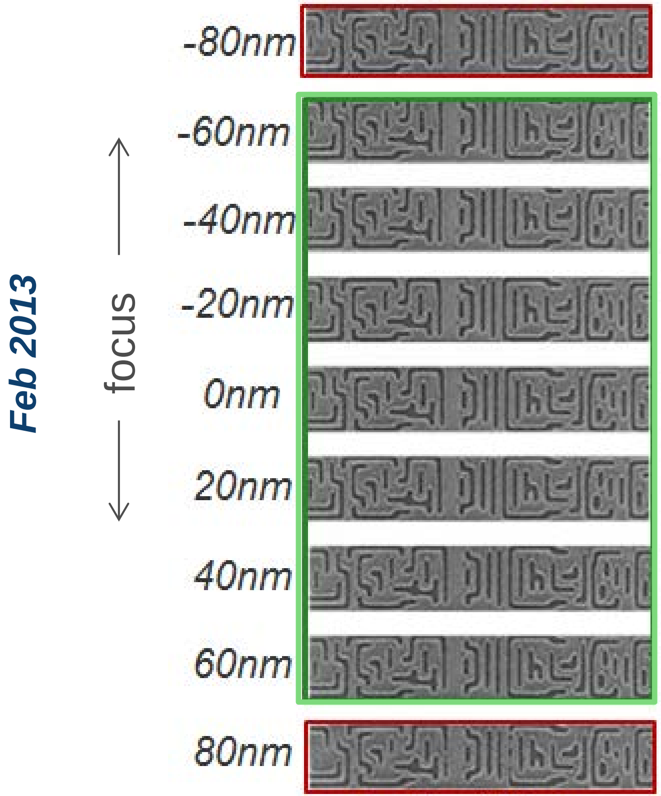
Good print performance over the full exposure slit

life.augmented

EUV single exposure 10nm Logic metal layer

45nm pitch, Conv.

Dose ~45mJ/cm2

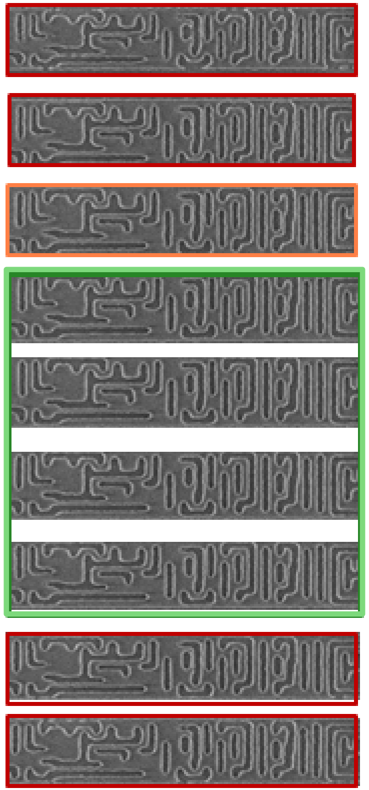


DoF ~ 120nm

- *Low dose resist*
- *Conventional setting*
- *DOF of 60-80nm*

45nm pitch, Conv.

Dose ~20mJ/cm2

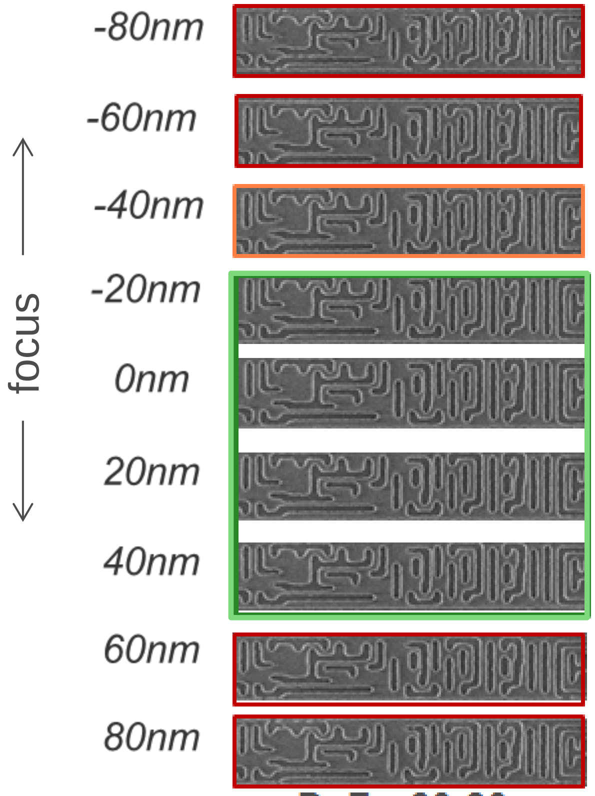


DoF ~ 60-80nm

EUV single exposure 10nm Logic metal layer

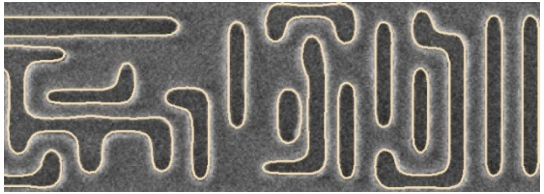
45nm pitch, Conv.

Dose ~20mJ/cm2



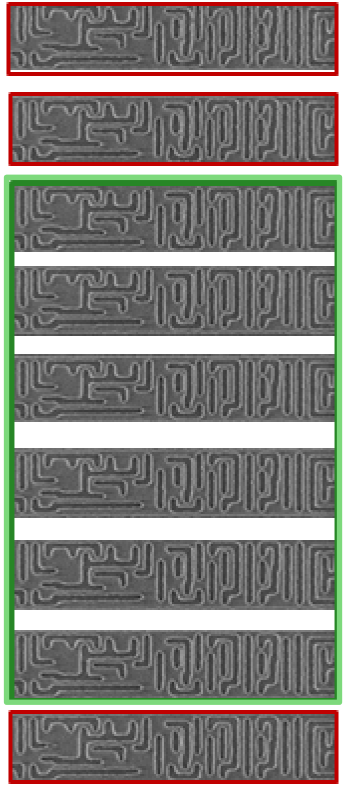
DoF ~ 60-80nm

- *Low dose resist*
- *Tachyon NXE OPC+*
- *Conventional setting*
- *DOF of 100nm*



45nm pitch, Conv.

Dose ~20mJ/cm2



DoF ~ 100nm

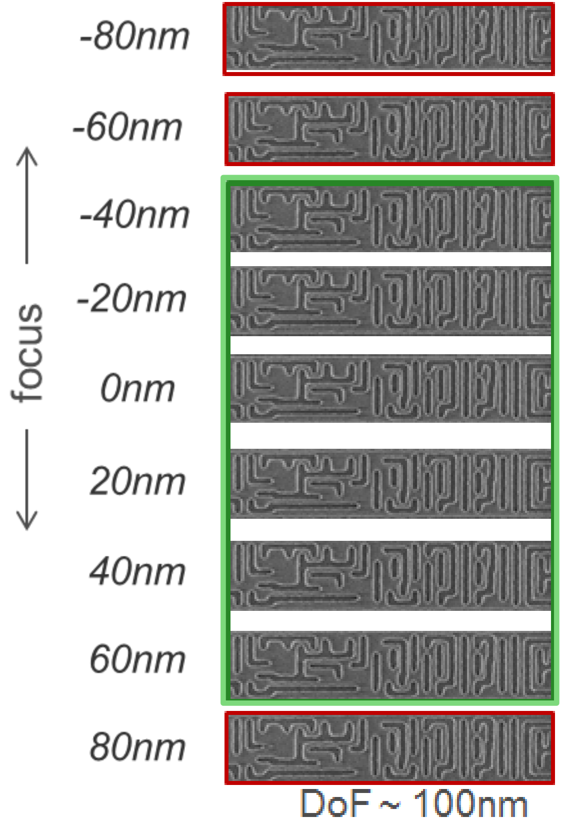
EUV single exposure 10nm Logic metal layer

Public

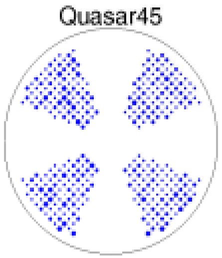
Slide 42

45nm pitch, Conv.

Dose ~20mJ/cm2

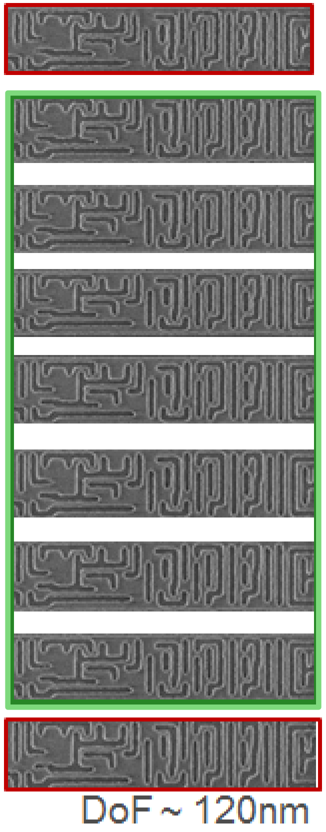


- *Low dose resist*
- *NXE OPC+*
- *Quasar 45 setting*
- ***DOF 120nm***



45nm pitch, Q45

Dose ~20mJ/cm2

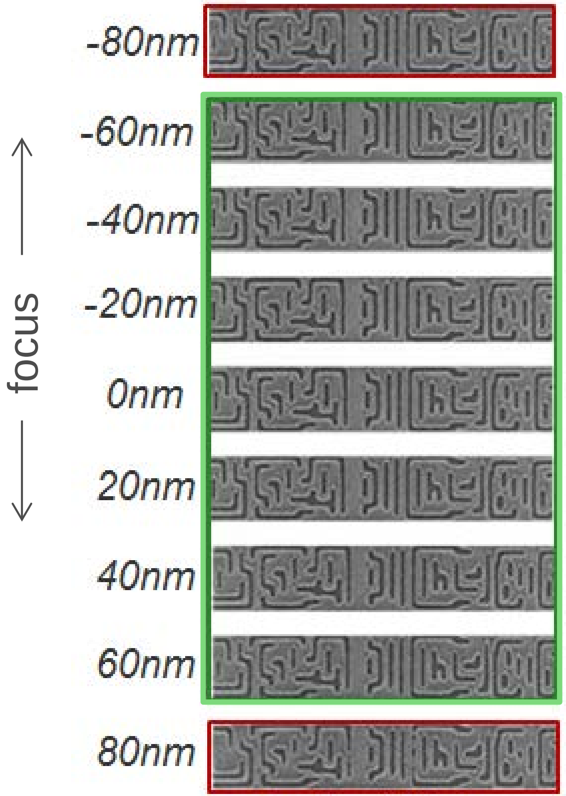


Excellent process window for 10nm Logic metal layer

Low dose, off axis illumination, NXE OPC+

45nm pitch, Conv.

Dose ~45mJ/cm2

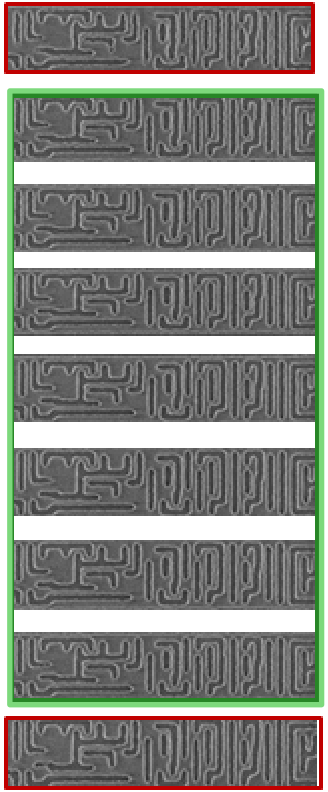


DoF ~ 120nm

- ***> factor 2 dose reduction***

45nm pitch, Q45

Dose ~20mJ/cm2



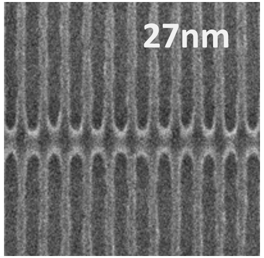
DoF ~ 120nm

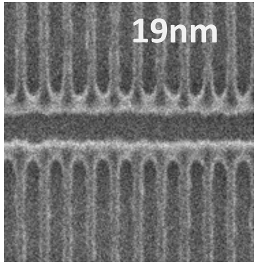
Contents

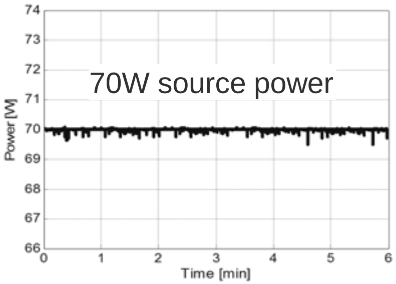
Summary

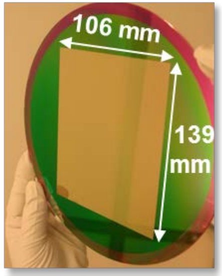
- **NXE:3100** in use for process and device development at customers

- **NXE:3300B** exposing wafers at customer sites
  - Multiple NXE:3300B system qualified and showing good imaging and overlay performance
  - Performance fit for customer development 10nm Logic and sub-20nm DRAM
  - Matched machine overlay (EUV to immersion) performance of <4nm shown on multiple systems
  - 70W MOPA-PP source power demonstrated with good dose control
  - Good defectivity performance shown on multiple systems at ASML in integration phase
  - Early results of new defectivity PRPi test show promising results
  - Progress continues in EUV pellicle development









First prototype full size free-standing pSi pellicle in progress

Acknowledgements

The work presented today, is the result of hard work and dedication of teams at ASML, Cymer, Zeiss, and many technology partners worldwide including our customers

Special thanks to our partners and customers for allowing us to use some of their data in this presentation